# Quantum Materials Studies at the *In-Situ* and Resonant Scattering Beamline, 4-ID

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# Scientific Programs and Beamline Specs

– Science focus areas:

- **Physics of quantum materials**
- Atomic structure of functional surfaces and interfaces
- Time-resolved studies of growth and materials processes

– Key capabilities:

- Tender and hard x-rays (2.4-23 keV)
- Variable focusing down to ~20 μm (H) x 2 μm (V)
- Polarization control
- Custom endstations, including gas handling system infrastructure

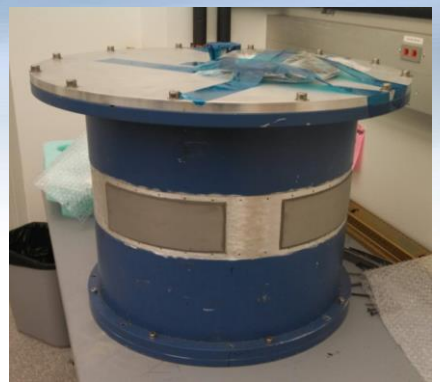
| Parameter | Specification/Description |
|---|---|
| Insertion device: | IVU23, 2.8-m long, in a high-β straight |
| Operating energy range: | 2.4 – 23 keV |
| Monochromator: | Fixed-exit Si(111) |
| Beam size at sample (FWHM): | Tunable down to 20 (H) x 2 (V) $\mu m^2$ |
| Flux at sample (500 mA ring current): | ~$10^{13}$ photons/s |
| Harmonic suppression: | ~$10^{-5}$ for third harmonic with fundamental at 3 keV |
| Polarization control: | $P_{L,C} \geq 0.9$ for 2.4 keV ≤ E ≤ 14 keV |
| **Custom endstations:** | **3 endstations: base diffractometer for high magnetic field studies, instrumented 6-circle diffractometer, and base diffractometer for *in-situ* studies of growth and materials processes with gas handling system infrastructure** |

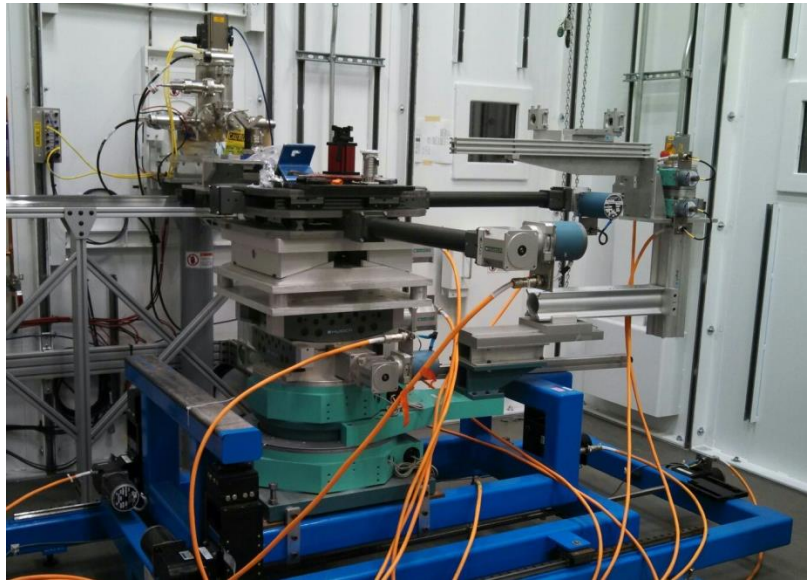
# Endstation Hutch 4-ID-C

## Instrumented 6-Circle Diffractometer

- Horizontal and vertical plane scattering with large accessible Q range
- Dual 2θ arms for simultaneous mounting of point and area detectors
- In-vacuum polarization analyzer
- Motorized cryostat carrier

## High-Field Magnet Endstation (to be commissioned in FY19)



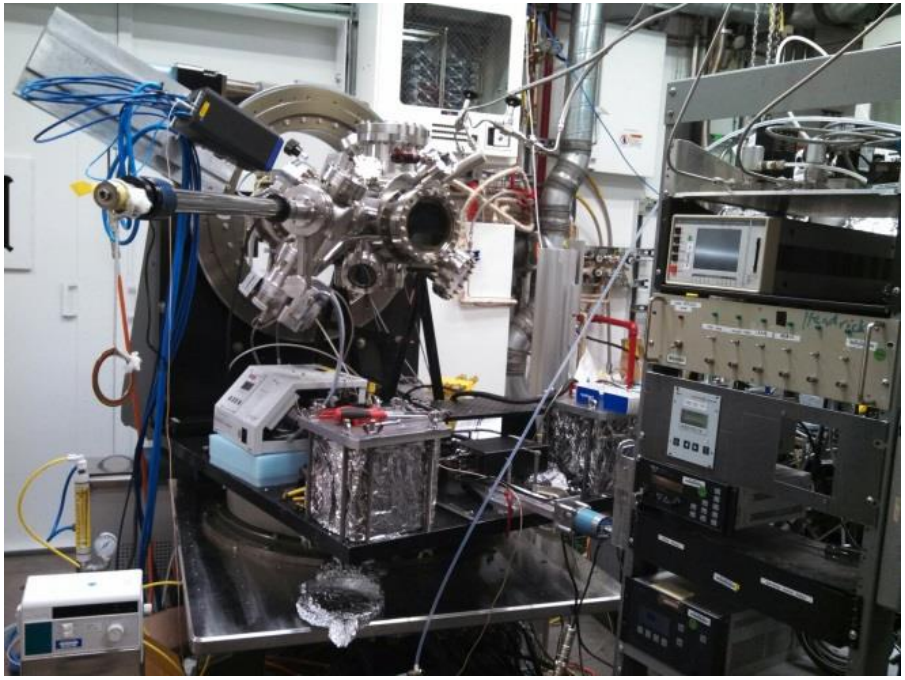


- Horizontal plane scattering
- Polarization analyzer
- Scattering magnet specifications:
  - Vertical field: up to ~10 T
  - Sample temperature: 1.8-300 K

# Endstation Hutch 4-ID-D

**Program contact:**
**Kenneth Evans-Lutterodt**

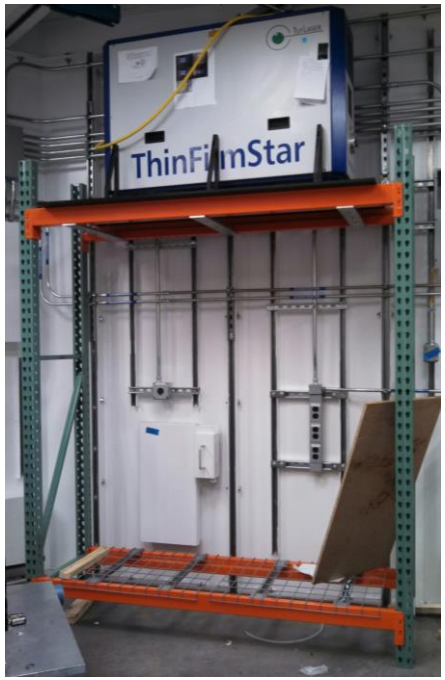
## *In-Situ* Diffractometer and Partner User-Supplied Growth Chamber



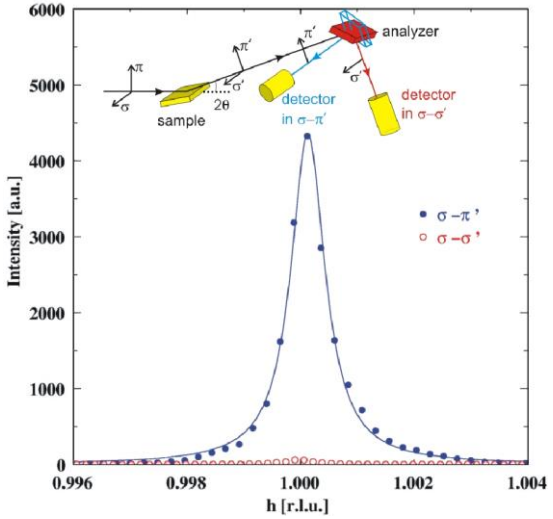
- Secondary focusing using KB mirrors
- Gas handling system
- Excimer laser
- Pixel array detector:
  - Millisecond time resolution
  - High Q resolution

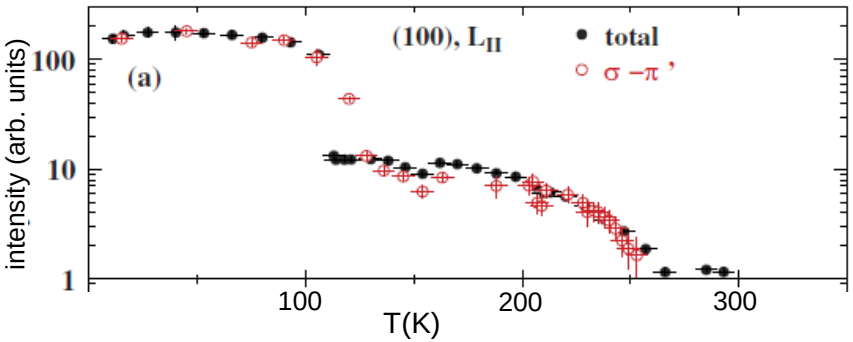
## Gas Cabinets

## Excimer Laser

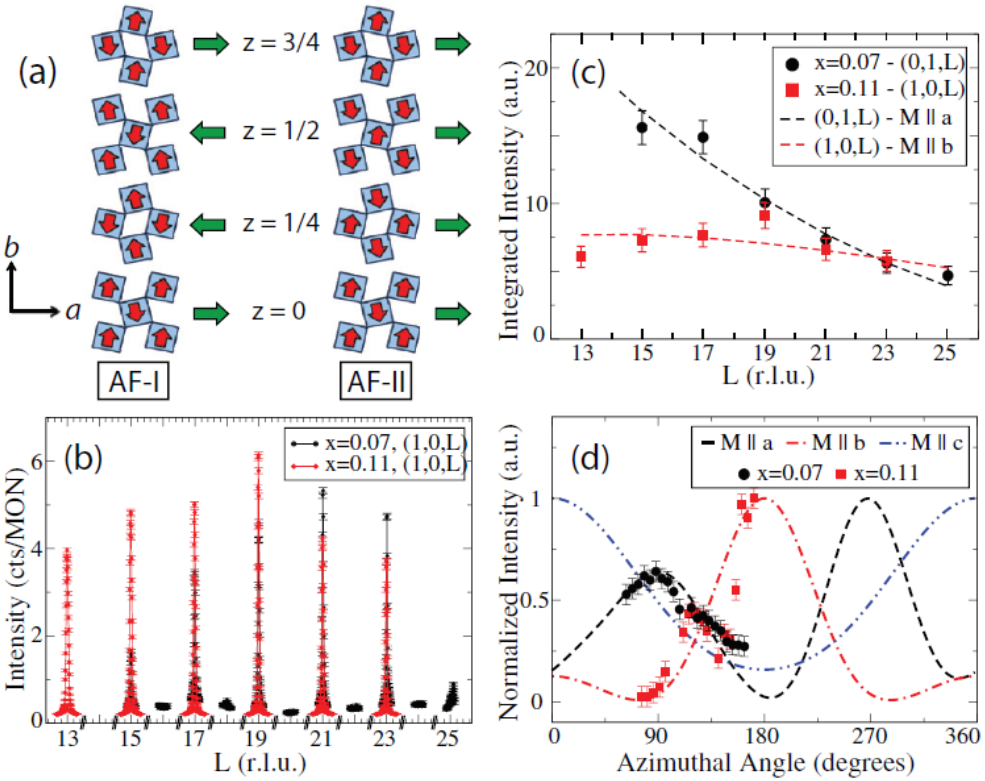


# Resonant X-ray Scattering from 4d- and 5d-based Oxides



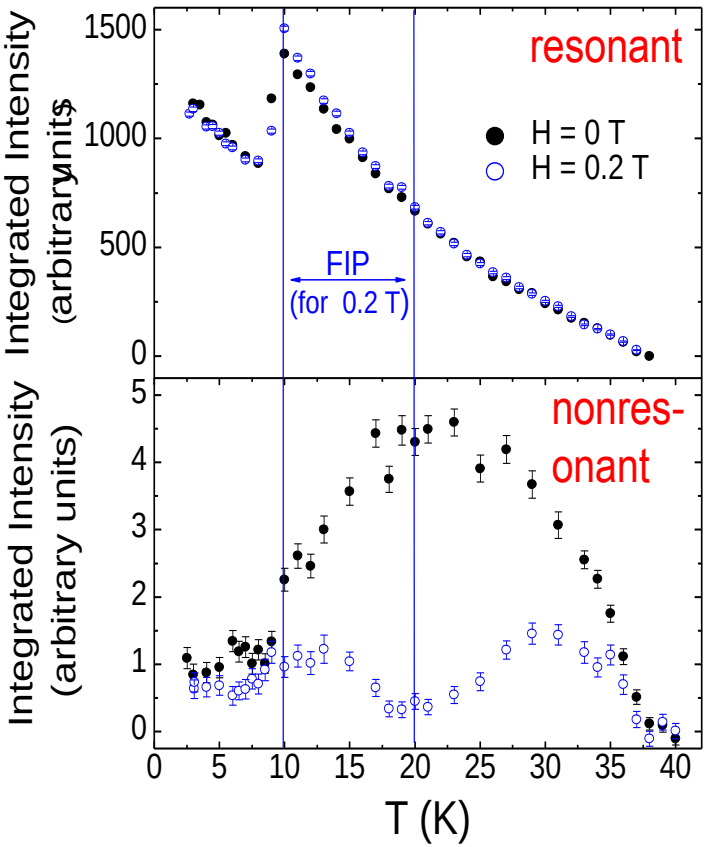



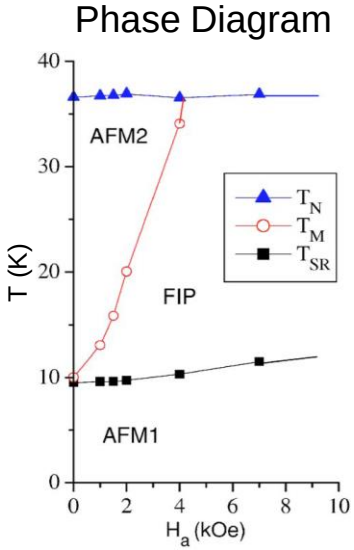

Orbital ordering transition observed in $Ca_2RuO_4$. Zegkinoglou *et al.*, PRL **95**, 136401 (2005).



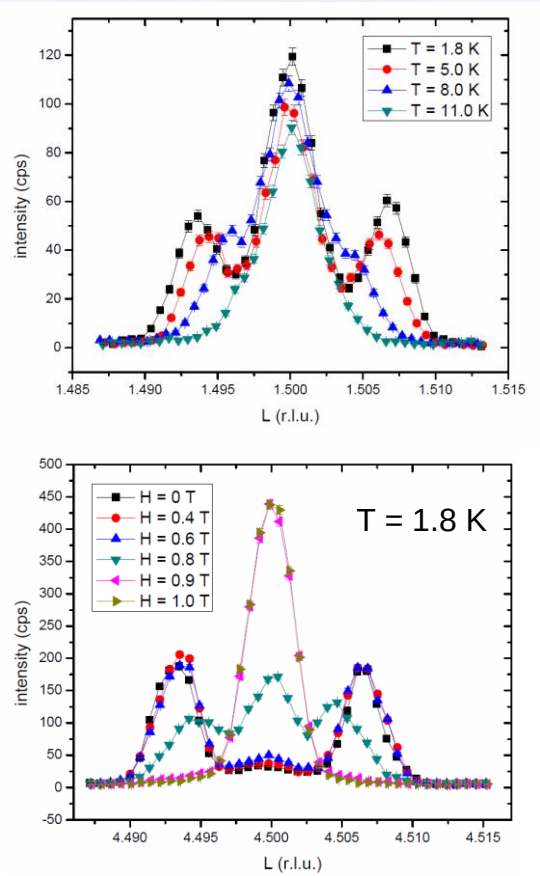

Characterization of doping-induced change in the magnetic order of $Sr_2Ir_{1-x}Rh_xO_4$. Clancy *et al.*, PRB **89**, 054409 (2014).

# Magnetic Order in Multiferroic Rare Earth Ferroborates




from Yen *et al.*, PRB **73**, 054435 (2006)



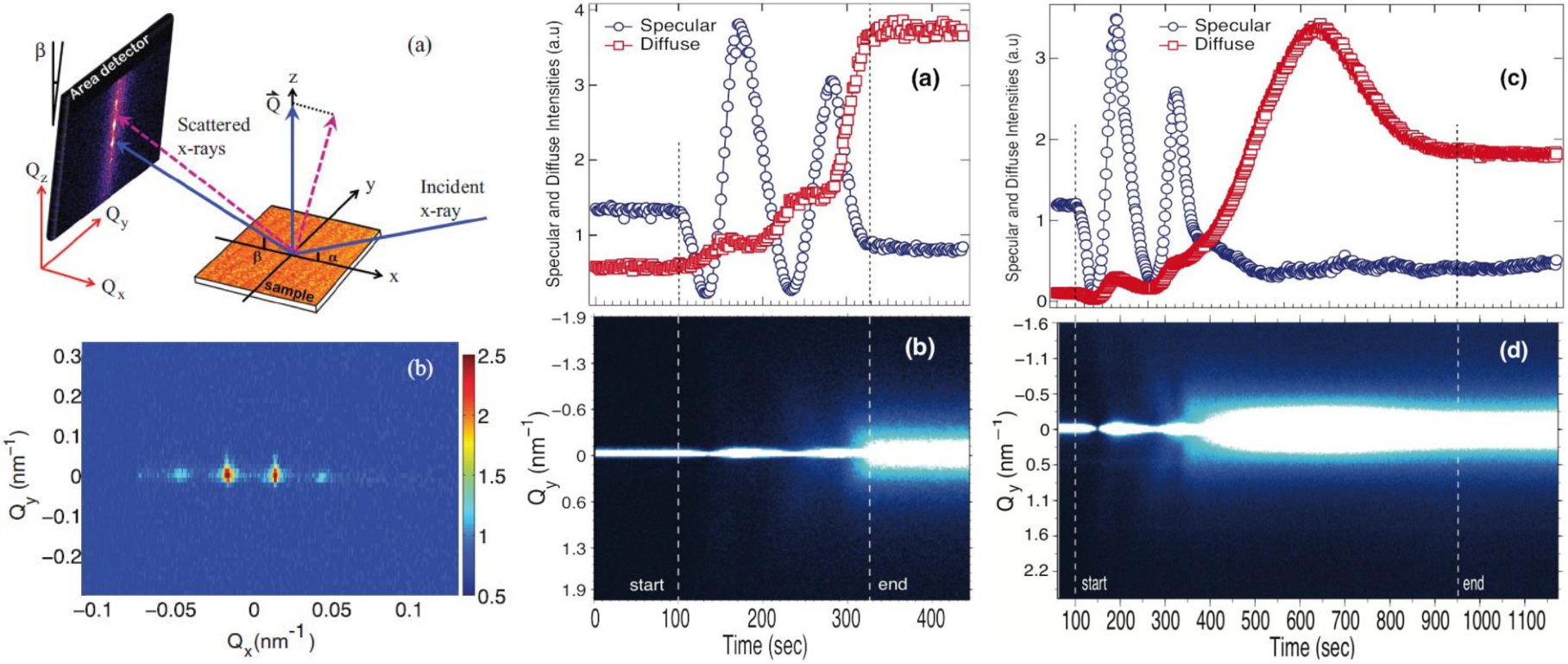

Magnetic structure of **$GdFe_3(BO_3)_4$** solved using magnetic x-ray scattering. Mo *et al.*, PRB **78**, 214407 (2008).

Temperature- and magnetic field-tuning of magnetic phases in **$NdFe_3(BO_3)_4$**. Nelson *et al.*, JKPS **62**, 1410 (2013).

# *In-Situ* Studies of $BiFeO_3$ Thin Film Growth

5 Hz Laser Repetition Rate

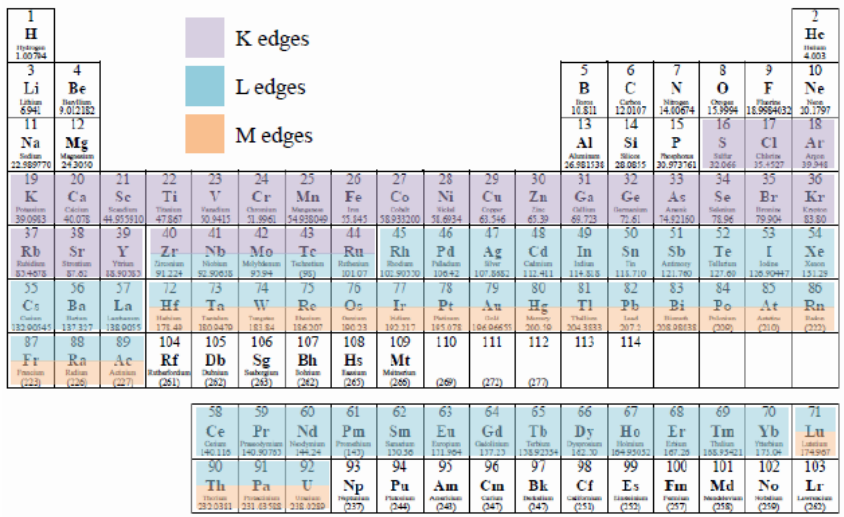
2 Hz Laser Repetition Rate




Laminar-to-3D growth mode transition at ~2.5 unit cells in pulsed laser deposited $BiFeO_3$. Chinta *et al*., APL **101**, 201602 (2012).

# Current and Near-Future Beamline Capabilities

Accessible Edges in ISR Energy Range (2.4-23 keV)




- Single-crystal resonant x-ray scattering with hard (6-23 keV) x-rays, ~100 μm beam
- *In-situ* studies of materials growth at surfaces and interfaces with hard x-rays (8-23 keV), with optional use of gas flow control and handling capabilities for non-hazardous gases, ~100 μm beam
- Secondary focusing down to ~20 μm (H) x 2 μm (V) with *in-situ* endstation (available in early 2018)
- Polarization control with hard (6-14 keV) x-rays (available in early 2018)
- Tender (2.4-6 keV) x-ray scattering with harmonic rejection and polarization control (available in late 2018)
- Growth processes using hazardous gases (available in 2019)
- Scattering in high magnetic field (available in 2019)

# Planned Additional Capabilities

- Sub-100 μm horizontal focusing for 6-circle diffractometer
- Coherent scattering:
  - Dynamics of charge, orbital, and magnetic domains
  - Domain imaging
- XMCD (requires horizontal magnetic field)
- Diamond anvil cell in high-field magnet